Cryogenic Instrumentation and Slow Controls Joint Consortium: Status & Plans

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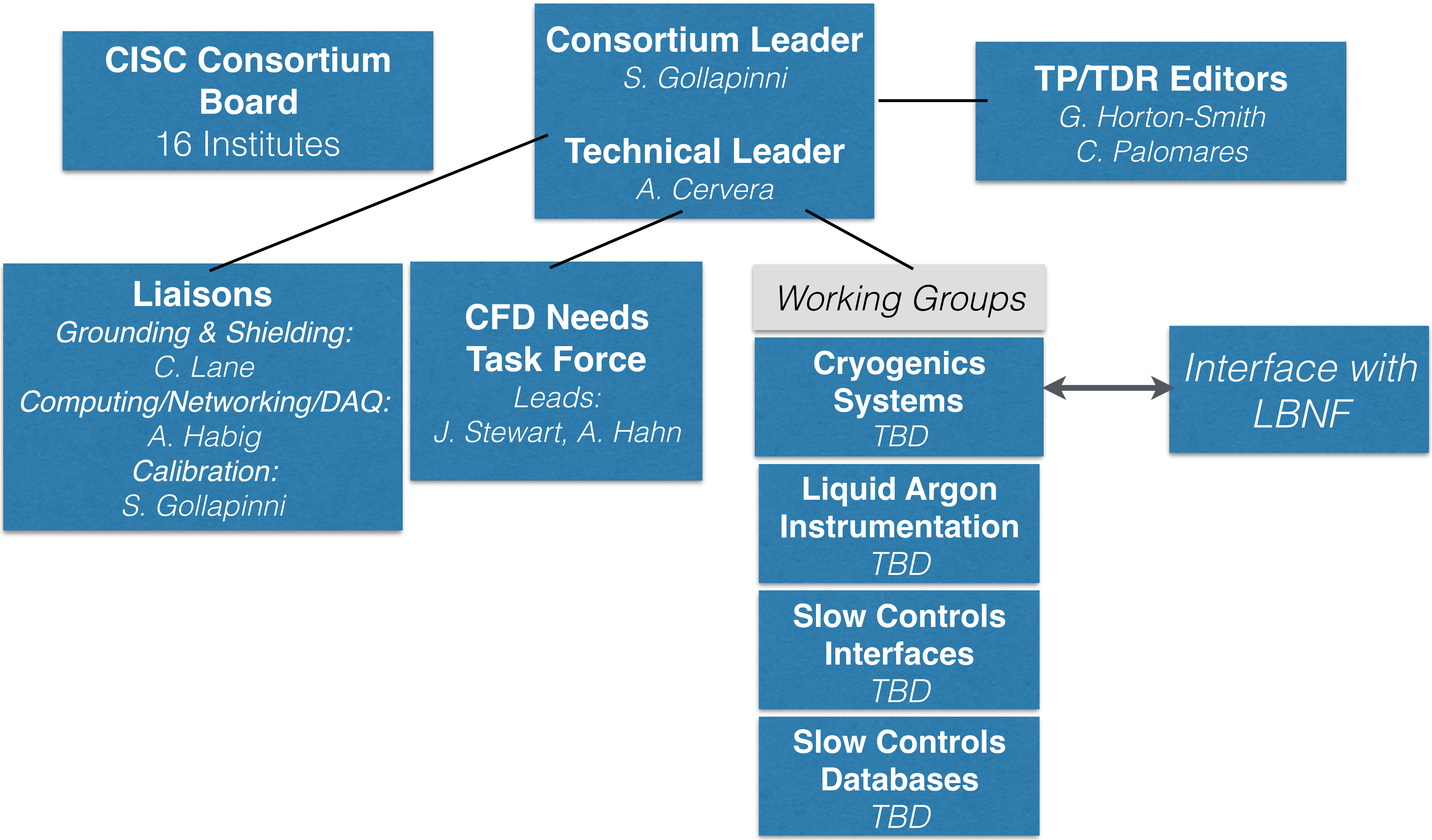
LBNC Review Meeting
Feb. 19, 2018
Fermilab

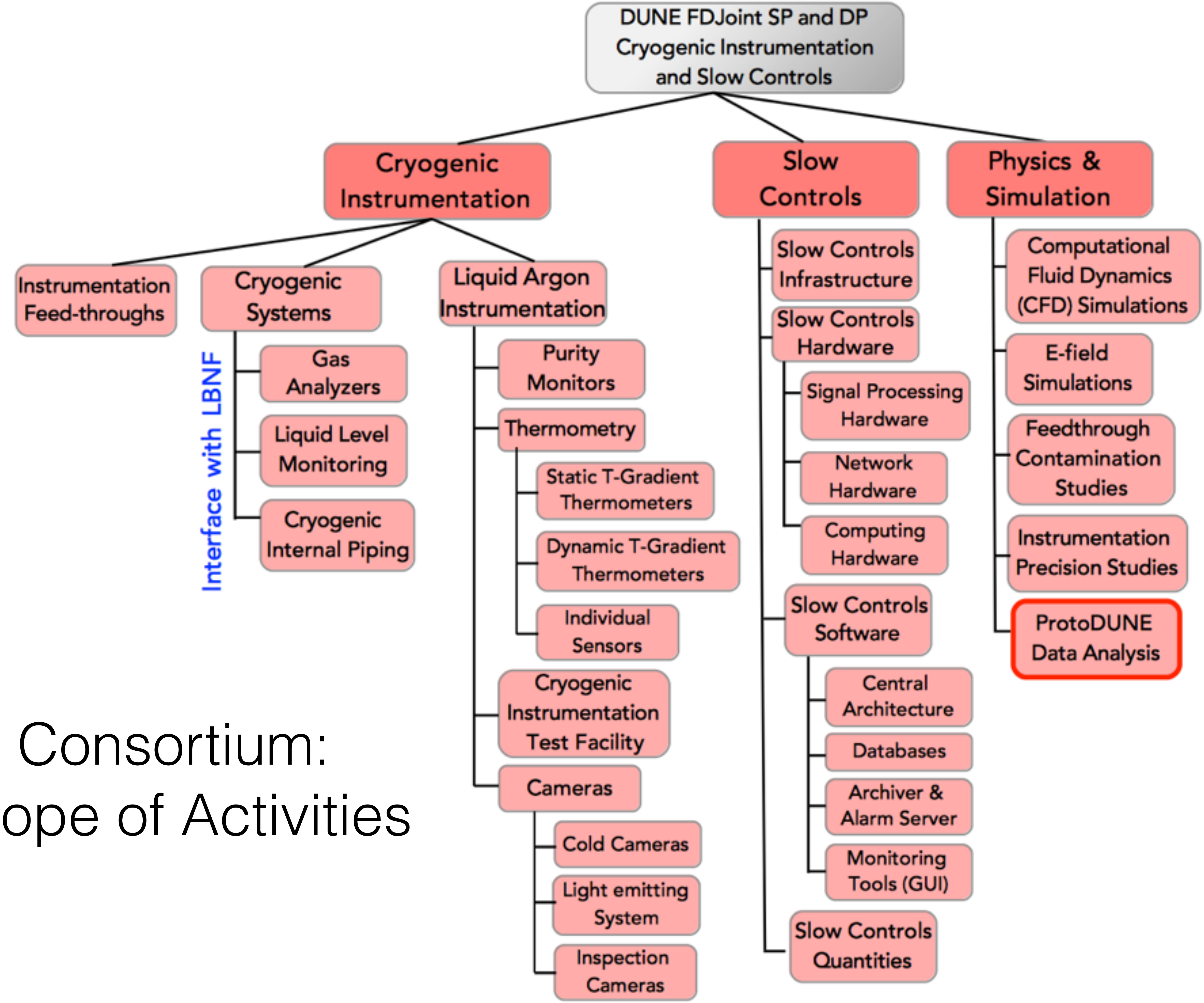
CISC Consortium

- CISC = Cryogenic Instrumentation and Slow Controls
- Joint consortium between Single-Phase and Dual-Phase
- Active weekly meetings
- Indico Page: https://indico.fnal.gov/category/702/
- 16 Institutes: 2 UK, 2 Spain, 12 US

U.S.A.		U.K.	Spain
Houston	ANL	UC London	CIEMAT
Idaho State	BNL	Warwick	IFIC (Valencia)
Kansas State	UC Irvine		
Minnesota	Drexel		
NotreDame	FNAL		
Tennessee	Hawaii		

CISC Internal Organization

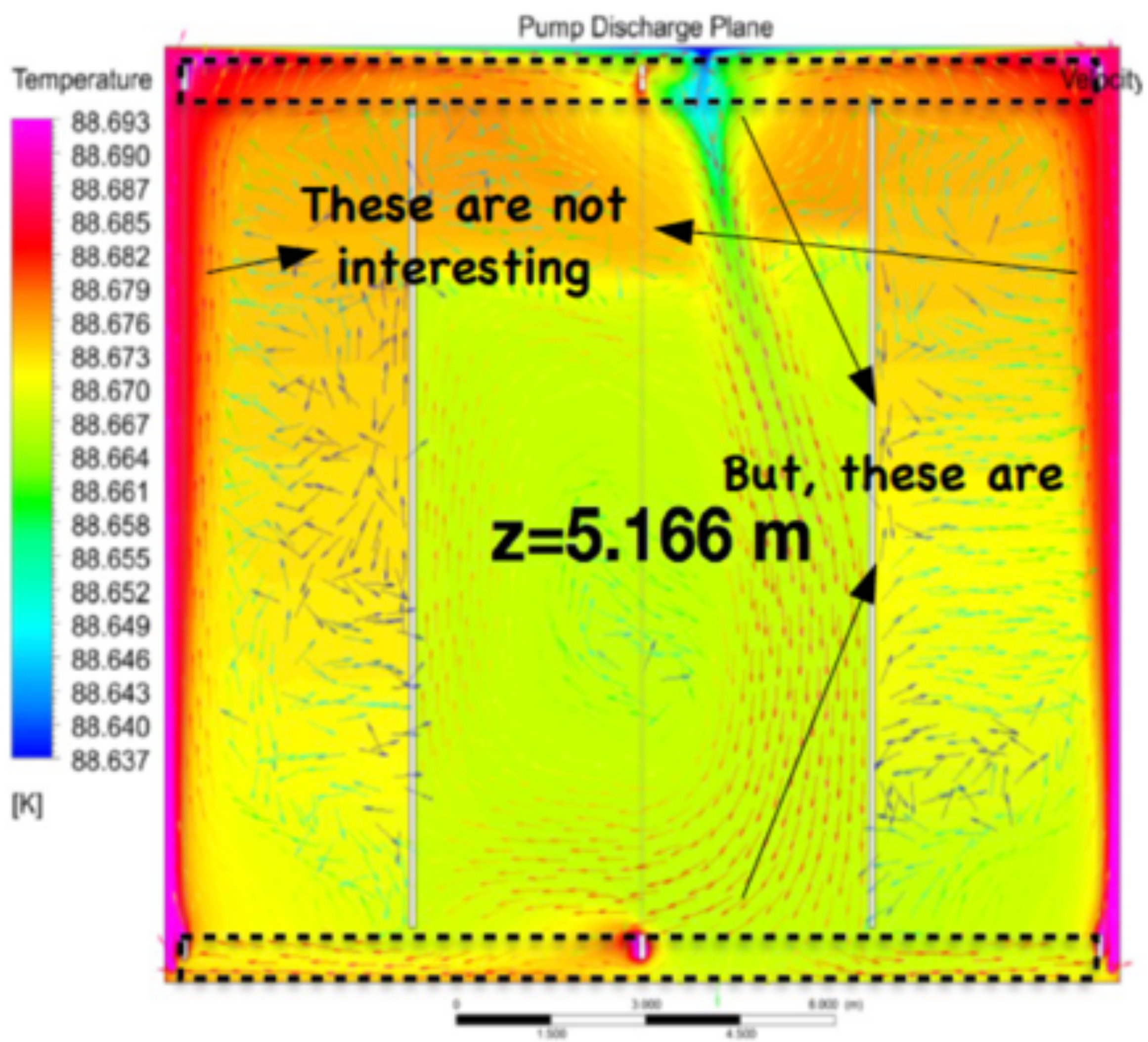


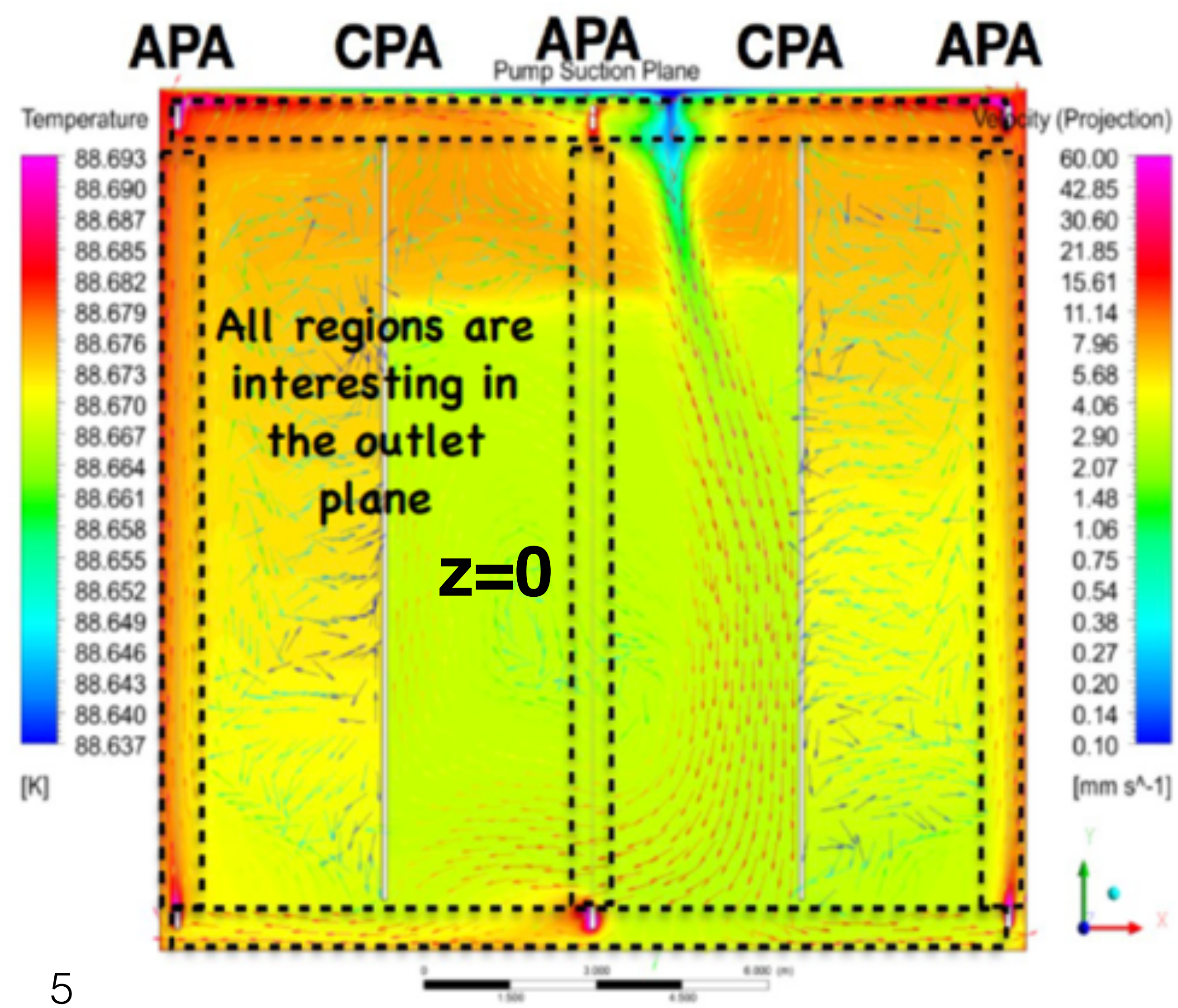


Consortium: Scope of Activities

CFD Simulations

- CFD simulations are important to understand
  - Internal Cryogenics Piping design
  - guide the design of instrumentation devices (e.g. no. of devices, location & distribution)
  - instrumentation data and correlate different devices
- Currently working to define a list of CFD needs from the instrumentation side





Key Interfaces

- Given the scope of our activities, we interface with almost every other Consortium
  - First round of Interface documents (11 documents, one for each group) produced: https://docs.dunescience.org/cgi-bin/private/ShowDocument?docid=6383
  - (strong interface) *LBNF and Infrastructure/Facilities* (cryogenics systems locations & anchoring points, rack space/packaging, interlocks, cable routing, installation sequence etc.)
  - (strong interface) *Calibration* (port sharing, cable routing, LAr contamination, interlock bit monitoring for calibration devices and analysis of instrumentation data for calibration & physics)
  - *HV* (cameras & lighting system); *APA* (inspection cameras)
  - *PDS* (safety due to light from Purity Monitors, camera light systems)
  - *DAQ* (rack space, integration test stand, installation)

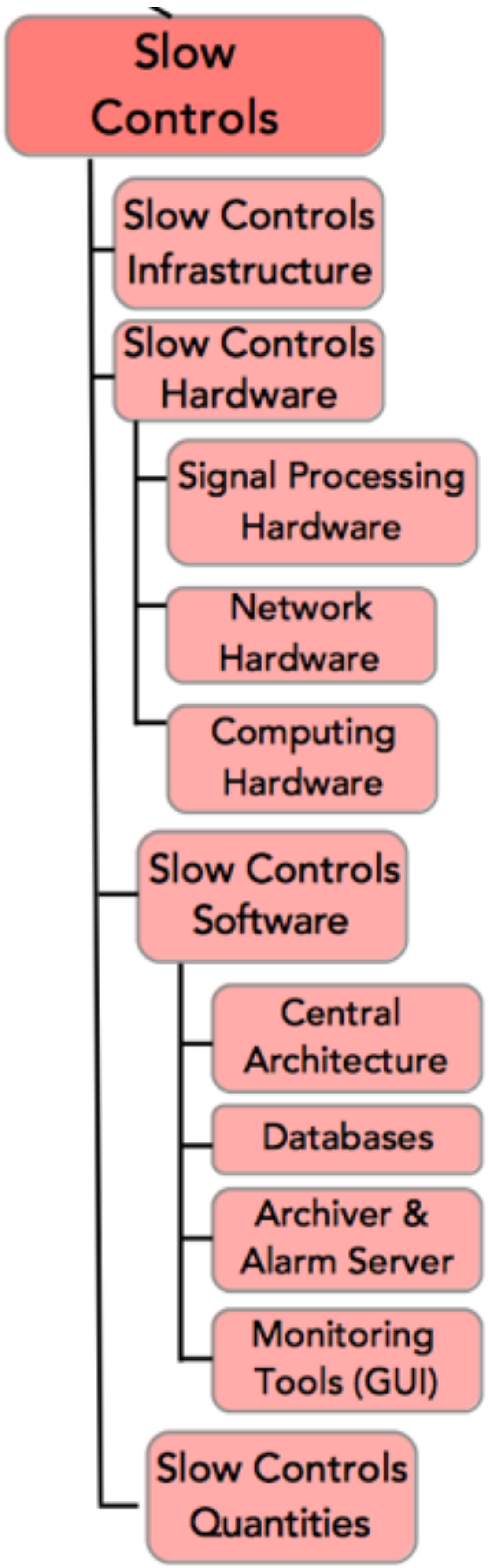
General Strategy: Cryogenic Instrumentation

- *Cryogenic Systems (Gas Analyzers, Liquid level monitoring, Internal Piping)*
    - Interface heavily with LBNF; Coordinate all activities/decisions
    - Consortium provides resources; effort/expertise driven by LBNF
- *Liquid Argon Instrumentation* (*Purity Monitors, Thermometers, Cameras, Test facility*)
    - For most, ProtoDUNE designs are considered as reference designs and can be extrapolated to DUNE
        - *Design validation, testing, calibration performance through ProtoDUNE data*
        - *Current focus is on instrumentation support structure and FT design*
    - Cold cameras & light emitting system require significant R&D — coordinating with ProtoDUNE SP & DP groups to push on that front
    - Test facility layout & design driven by experience and sub-system needs

General Strategy: Slow Controls

- *Sketch out DUNE needs/requirements* (e.g. no. of systems, channels, interfacing, central framework consideration etc.) *— In progress*
- Conduct a historical ***survey of frameworks from various experiments*** (LArTPC, non-LArTPC, small, big etc.) *— In progress*
- *Select an architecture* (Open source vs Commercial) that meets DUNE requirements
- On the signal processing, hardware/networking/ infrastructure side, ***interface with relevant consortia to ensure slow controls needs are taken into account*** *— in progress*

Nice overview talk at the Jan. Collaboration meeting
https://indico.fnal.gov/event/14581/session/7/contribution/96/material/slides/1.pdf



Main Requirements and Specifications

Full requirements: https://docs.dunescience.org/cgi-bin/private/ShowDocument?docid=6440
(a total of 53 requirements)

Parameter	Minimum Requirement	Comment
Max. E-field near Instrumentation devices	< 30 kV/cm	Maximum field that the LAr can maintain without undergoing dielectric breakdown.
Noise from instrumentation devices	ALARA	ALARA = As Low As Reasonably Achievable
Precision in electron lifetime measurement	<1.4%	per DUNE-FD Task Force, needed to keep the bias on the charge readout in the TPC to below 0.5% at 3 ms
Thermometers precision	< 5 mK	Driven by CFD simulation validation; based on ProtoDUNE-SP design
Vertical density of T-gradient monitors	> 2 sensors/meter	sufficient to measure gradients of 5 mK
2D horizontal density of top/bottom individual sensors	1 sensor/5(10)m	Transversely (1 every 5 m) Longitudinally (1 every 10 m); Ideally larger density: 1 every APA/CPA plane (3 meters) and longitudinally every 5 m

Most requirements/specifications based on extrapolations from ProtoDUNE designs and with the physics motivation of CFD simulation validation

Main Requirements and Specifications (Continued)

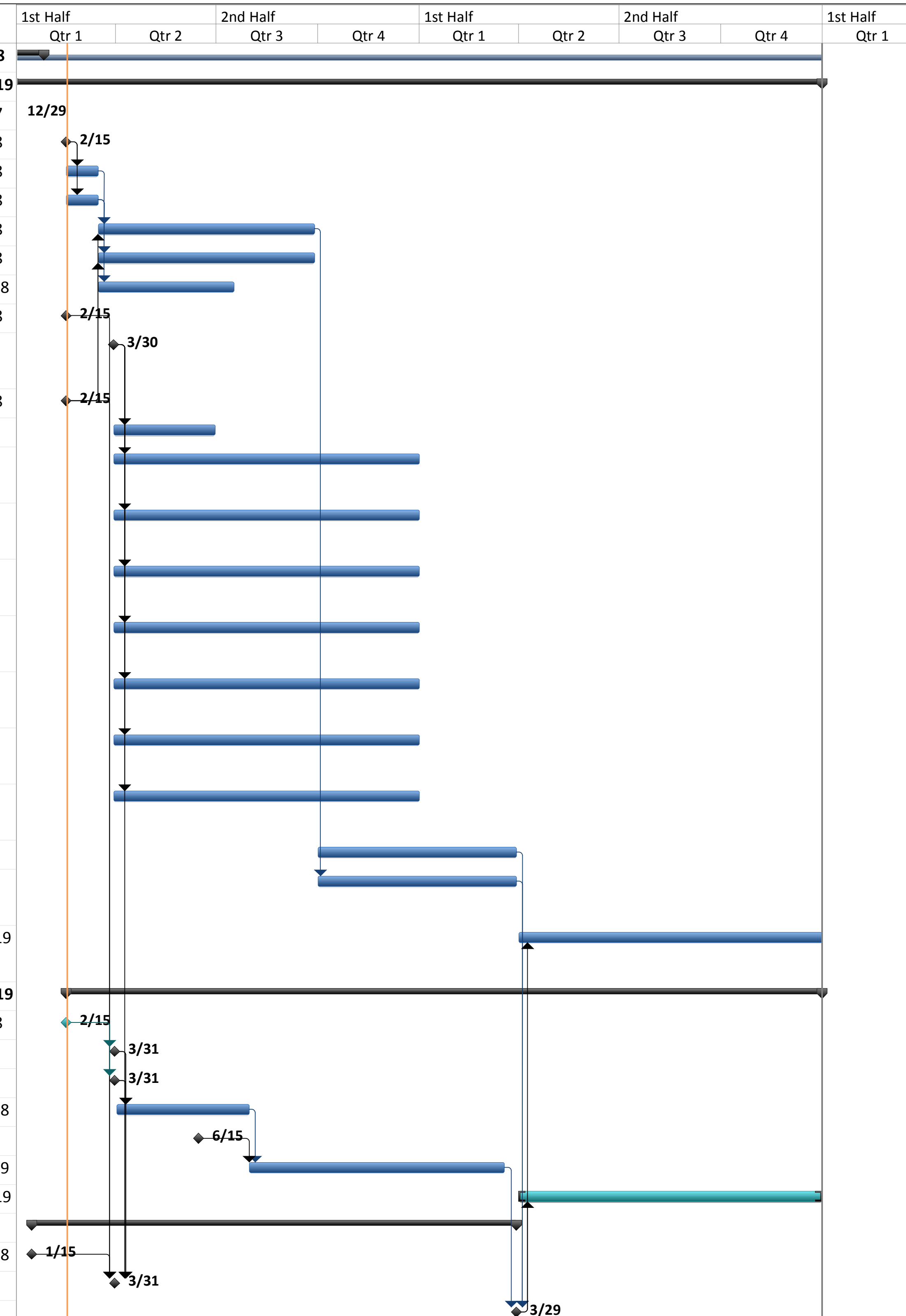
Parameter	Minimum Requirement	Comment
Liquid level meters precision	0.1 % over 14 m	Standard sensitivity; will use two level meters for redundancy
Cold cameras coverage	80% of the exterior of HV	To meet HV monitoring needs
Inspection cameras coverage	80% of the TPC	To meet APA wire plane monitoring needs
Cryogenic Instr. Test Facility: Dimenstions	0.5 to 3 cubic meters	Driven by filling costs and turn around times
Alarm rate	< 150/day	Recommended manageable alarm rate; allows experiment operators to "respond" to every alarm.
Total No. of Variables	50k to 100k	requires robust base software model that can handle large no. of variables
Archiving rate	Min. 0.02 Hz Range: 1 Hz to 1/few minutes	Impacts the base software model choice; will depend on data storage capabilities
Integrate ND status	Full Beam and Detector Status	Needed to operate as “one” detector

Key CISC Milestones leading to TDR

Date	Milestone
Dec. 2017	Finalize Cryostat Instrumentation Feedthroughs
Dec. 2017	Develop a baseline conceptual design/layout for the internal cryogenic piping
March 2018	Develop conceptual designs (including support structure) for all instrumentation devices
March 2018	Define Slow controls hardware/software requirements & Layout
April 2018	PrM design performance metrics for DUNE FD SP from ProtoDUNE-SP PrM tests in LAr
May 2018	Technical Proposal
Aug 2018	Use ProtoDUNE-SP instrumentation/operations data to validate designs
Nov. 2018	Finish producing needed E-field and CFD simulations
Dec. 2018	Full design of the cryogenic instrumentation test facility
Jan 2019	Develop a complete architectural design for Slow Controls
Feb 2019	Finalize designs all instrumentation devices
April 2019	Technical Design Report

Project Schedule

ID	WBS	Task Name	Duration	Start	Finish
6	**2**	**Slow Controls & Cryo Instrumentation Consortium**	**40 days**	**Fri 12/1/17**	**Thu 1/25/18**
7	**2.1**	**Cryogenic Instrumentation**	**523 days**	**Fri 12/29/17**	**Tue 12/31/19**
8	2.1.1	Finalize FT requirements/locations for Instrumentation devices	0 days	Fri 12/29/17	Fri 12/29/17
9	2.1.2	Form a CFD steering group that will guide the next steps for CFD for the consortium	0 days	Thu 2/15/18	Thu 2/15/18
10	2.1.3	Produce list of needed CFD simulations	21 days	Thu 2/15/18	Thu 3/15/18
11	2.1.4	Produce list of E-field simulations needed for Instrumentation design	21 days	Thu 2/15/18	Thu 3/15/18
12	2.1.5	Perform needed CFD Studies	140 days	Fri 3/16/18	Thu 9/27/18
13	2.1.6	Produce needed E-field simulation studies for instrumentation designs	140 days	Fri 3/16/18	Thu 9/27/18
14	2.1.7	Perform E-field Shielding studies for Instrumentation designs for DP	87 days	Fri 3/16/18	Mon 7/16/18
15	2.1.8	Define preliminary hardware/software/mechanical interfaces	0 days	Thu 2/15/18	Thu 2/15/18
16	2.1.9	Define requirements for Instrumentation devices (No. of devices, locations, Sensitivity requirements etc.)	0 days	Fri 3/30/18	Fri 3/30/18
17	2.1.10	For Internal Cryogenic Piping, converge on a conceptual design and layout	0 days	Thu 2/15/18	Thu 2/15/18
18	2.1.11	Investigate applicability of SP instrumentation designs to DP detector	66 days	Fri 3/30/18	Fri 6/29/18
19	2.1.12	Develop design for Purity Monitors (including support system and feedthroughs) from ProtoDUNE reference	197 days	Fri 3/30/18	Mon 12/31/18
20	2.1.13	Develop design for Static T-Gradient Thermometers (including support system and feedthroughs) from ProtoDUNE reference	197 days	Fri 3/30/18	Mon 12/31/18
21	2.1.14	Develop design for Dynamic T-Gradient Thermometers (including support system and feedthroughs) from ProtoDUNE reference	197 days	Fri 3/30/18	Mon 12/31/18
22	2.1.15	Develop design for Individual Sensors (including support system and feedthroughs) from ProtoDUNE reference	197 days	Fri 3/30/18	Mon 12/31/18
23	2.1.16	R & D to develop design for Cold Cryogenic Cameras (including support system and feedthroughs)	197 days	Fri 3/30/18	Mon 12/31/18
24	2.1.17	R & D to develop design for Warm Inspection Cameras (including support system and feedthroughs)	197 days	Fri 3/30/18	Mon 12/31/18
25	2.1.18	R & D to develop design for Light Emitting System (including support system and feedthroughs)	197 days	Fri 3/30/18	Mon 12/31/18
26	2.1.19	Validate FD SP Instrumentation designs with ProtoDUNE-SP instrumentation data	130 days	Mon 10/1/18	Fri 3/29/19
27	2.1.20	Determine FD Fluid flow map using Thermometry data from ProtoDUNE-SP & CFD studies	130 days	Mon 10/1/18	Fri 3/29/19
28	2.1.21	Evolve/Finalize Instrumentation design including support systems and Feedthroughs (based on performance from ProtoDUNE-SP data)	197 days	Mon 4/1/19	Tue 12/31/19
29	**2.2**	**Slow Controls**	**489 days**	**Thu 2/15/18**	**Tue 12/31/19**
30	2.2.1	Define slow controls mechanical and software interfaces	0 days	Thu 2/15/18	Thu 2/15/18
31	2.2.2	Define slow controls hardware requirements & layout	0 days	Sat 3/31/18	Sat 3/31/18
32	2.2.3	Define slow controls software/firmware requirements	0 days	Sat 3/31/18	Sat 3/31/18
33	2.2.4	Specify requirements for common rack layout and packaging	86 days	Mon 4/2/18	Mon 7/30/18
34	2.2.5	Define Slow Controls interface to detector safety systems	0 days	Fri 6/15/18	Fri 6/15/18
35	2.2.6	Further development of Slow Controls architecture	165 days	Tue 7/31/18	Mon 3/18/19
36	2.2.7	Evolve/Finalize slow controls architecture	197 days	Mon 4/1/19	Tue 12/31/19
37	**2.3**	**TP/TDR**	**315 days**	**Mon 1/15/18**	**Fri 3/29/19**
38	2.3.1	TP/TDR outline and table of contents (down to section headings) defined	0 days	Mon 1/15/18	Mon 1/15/18
39	2.3.2	Prepare & Submit Technical Proposal for internal review	0 days	Sat 3/31/18	Sat 3/31/18
40	2.3.3	Prepare & Submit first complete draft of TDR for internal review	0 days	Fri 3/29/19	Fri 3/29/19



Project: FD Int schedule
Date: Fri 2/16/18

Task	Project Summary	Inactive Milestone	Manual Summary Rollup	Deadline
Split	External Tasks	Inactive Summary	Manual Summary	Progress
Milestone	External Milestone	Manual Task	Start-only	
Summary	Inactive Task	Duration-only	Finish-only	

Key Risks and Concerns

Full list: https://docs.dunescience.org/cgi-bin/private/ShowDocument?docid=7192

(a total of 22 concerns)

Note: These risks/concerns have possible mitigation strategies identified, see backup s22

- The baseline design (extrapolated from ProtoDUNEs) for any of the instrumentation devices is not adequate for DUNE far detectors
- Ensuring longevity of devices for 20+ years
- Instrumentation devices can induce noise in cold electronics
- Discrepancies between measured temperature map and CFD simulations in ProtoDUNE-SP
- The baseline design of the Cryogenics Instrumentation Test Facility (CITF) is not able to accommodate some of the alternative designs mentioned (related to risk 1)
- During R&D phase the CISC consortium is not able to build a working prototype for cold cameras that meet all the requirements & safety
- HV Discharge caused by cameras and other devices; HV discharge destroying cameras
- Lack of involvement/expertise and insufficient input from past experience for DP technology

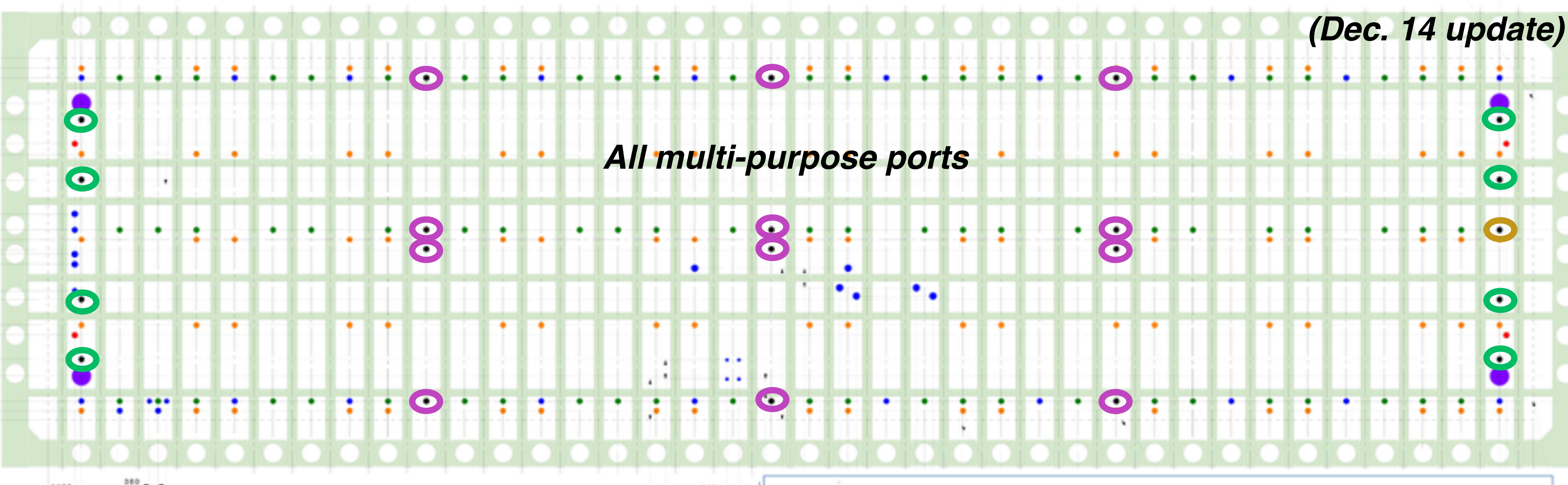
Backup

Initial Focus: Instrumentation Feedthroughs

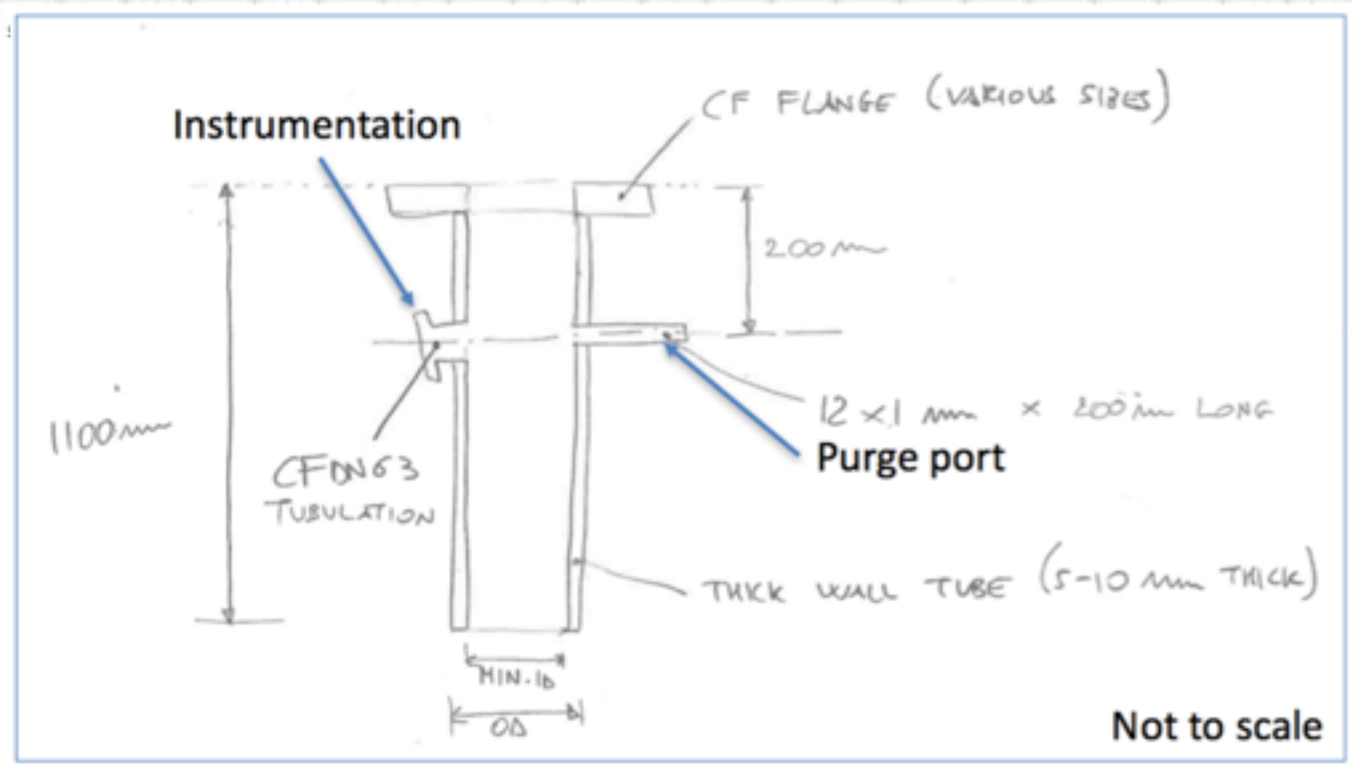
= Calibration/Instrumentation

= Instrumentation FT

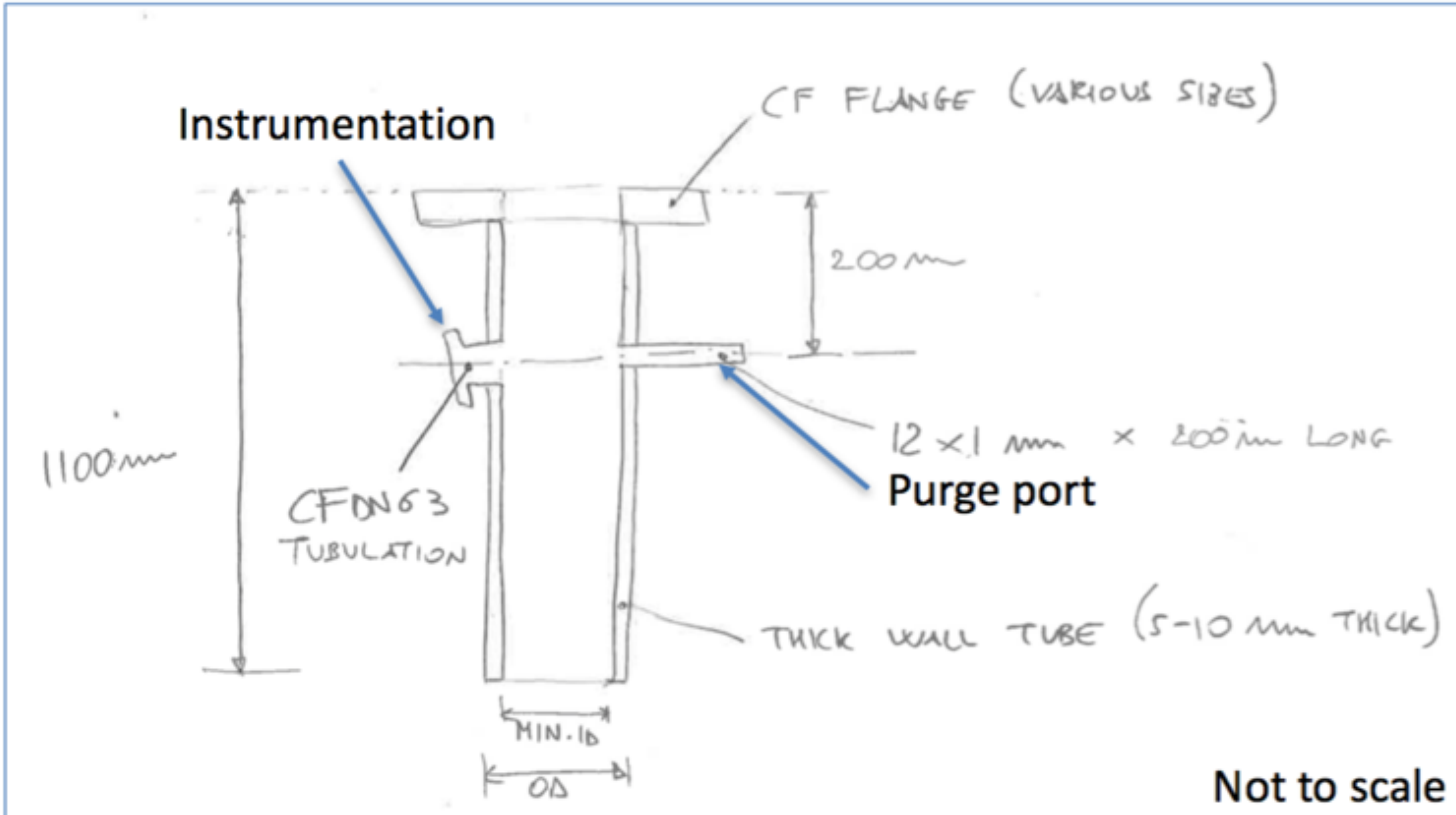
Thanks to E. James, J. Fowler and M. Nessi for all the help!



Pos.	Diameter [mm]	Quantity	Description
1	Ø250	100	Support
2	Ø250	75	Cable
3	Ø250	4	High voltage
4	Ø250	21	Instrumentation
5	Ø800	4	Manholes

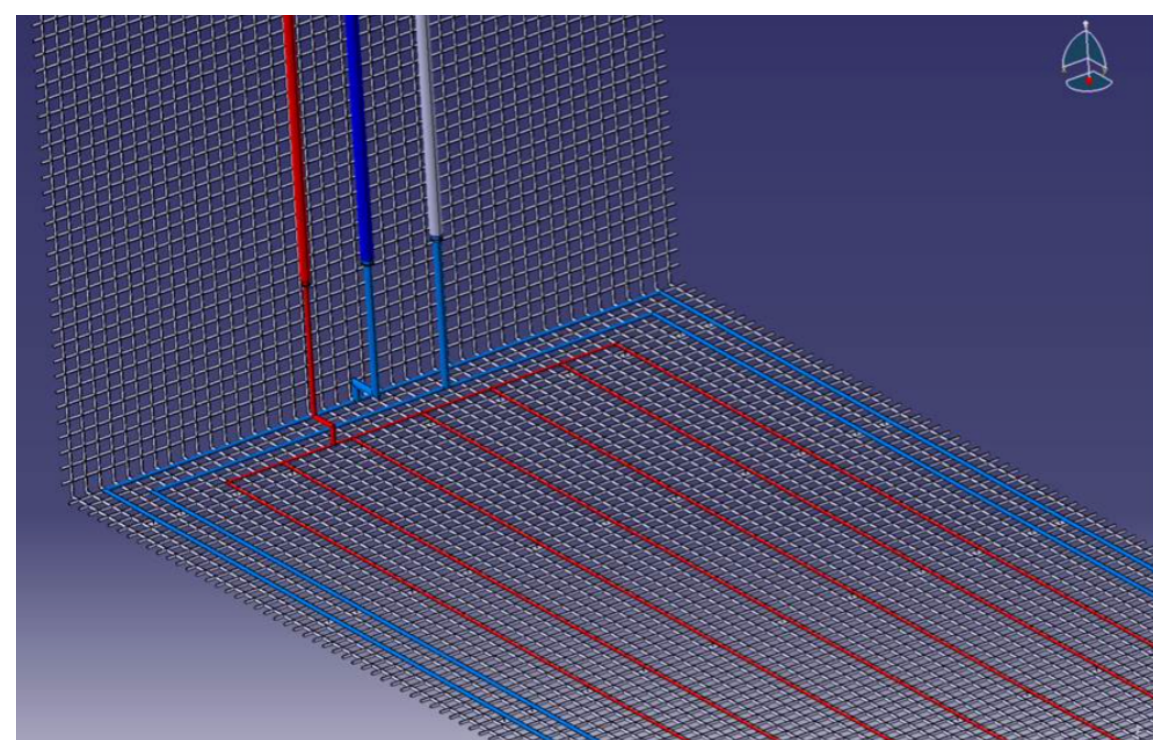


Feedthrough design (J. Fowler)



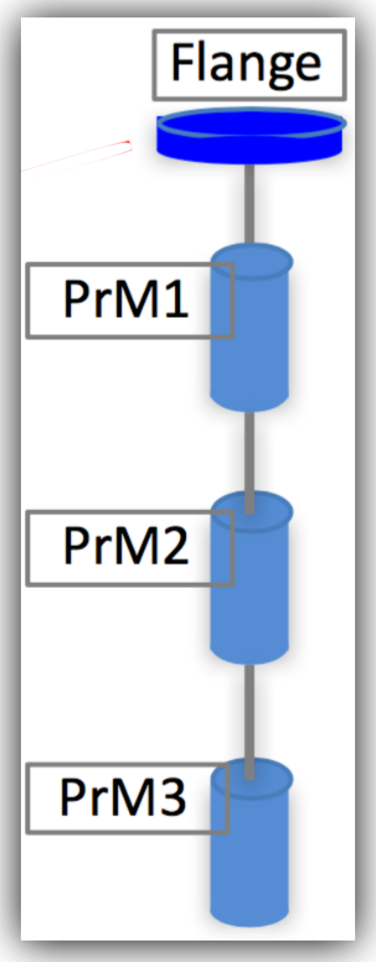
Cryogenics Systems

- *Gas Analyzers:*
  - Plan is to use a common set of commercially available gas analyzers to monitor water, oxygen and nitrogen during the purge phase and as needed during the long-term cryogenic operations
  - Effort largely shared b/n DUNE and LBNF; Same set of analyzers will be used for SP and DP
  - Most likely located in a movable rack in the mezzanine (need to finalize the location of the panel
- *Liquid Level Monitors:* Two commercially available differential pressure level monitors will be provided by LBNF, each with a precision of about 0.1% over 14 m. Two level meters are used for redundancy.
- *Internal Cryogenic Piping*
  - Baseline design finalized by LBNF
  - As in ProtoDUNE-SP, the bottom temperature sensors will anchoring points



Purity Monitors

- Fast detection of liquid argon impurities
- Follow ProtoDUNE-SP design with 3 purity monitors hanging from a flange
- Use two of those arrays on each end of the cryostat
- Inline purity monitors to monitor the liquid argon filtration
- Need R&D related to Mechanics
  - Extrapolation from 8 to 15 m not obvious
  - Support structure design, FT design
  - E-field shielding, mainly for DP
- Understand performance metrics from ProtoDUNE-SP PrM tests in LAr (April timeline)



Temperature Monitors

- High precision (<5 mK) 3D temperature map of the cryostat.
    - Crucial to ensure LAr recirculation & LAr uniformity is as expected; validate fluid flow model
- *Extrapolate from ProtoDUNE-SP*. Three types of devices
    - Static T-Gradient Monitor: Vertical array with laboratory calibration
    - Dynamic T-Gradient Monitor: Vertical array with in-situ calibration
    - Individual sensors: Coarser horizontal 2D array at top and bottom
- *Need R&D for mechanics (support structure etc.)*
- *Desirable FT locations from analysis of CFD and liquid argon inlet and outlet design*

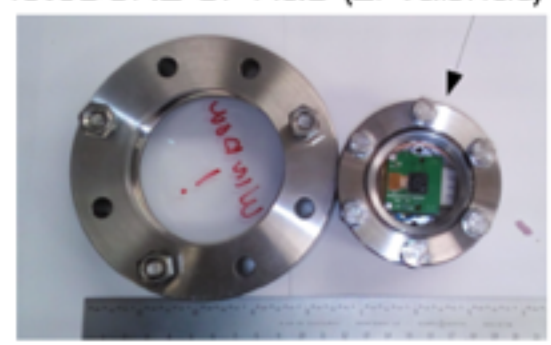
- Start (August 2018) analyzing ProtoDUNE-SP instrumentation/Operations data to validate the design

Cameras

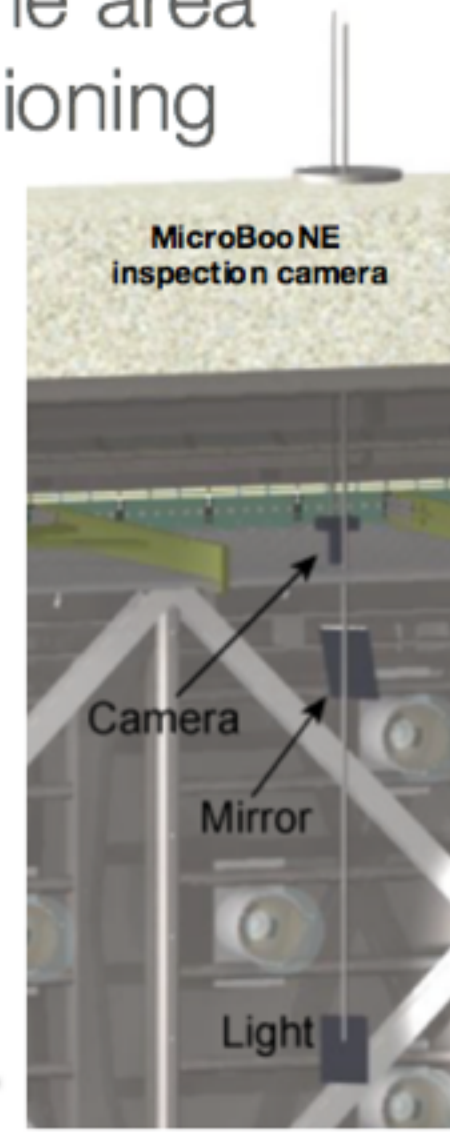
- Monitoring of HV Feedthrough, top/bottom ground plane area around APAs, and general monitoring during commissioning

camera housing and heaters are crucial

ProtoDUNE-SP R&D (E. Valencia)

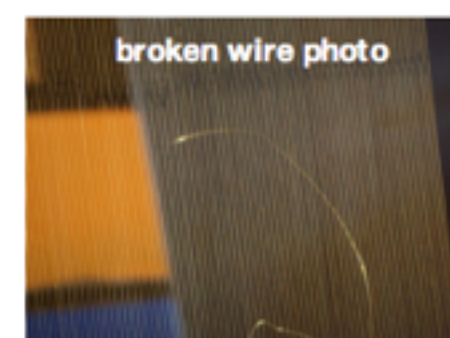


- Cold cameras
  - Significant R&D needed since no successful prototype exists
- Inspection (warm) cameras
  - Steerable Periscope style hanging from flange
  - Could follow MicroBooNE design https://arxiv.org/abs/1507.02508



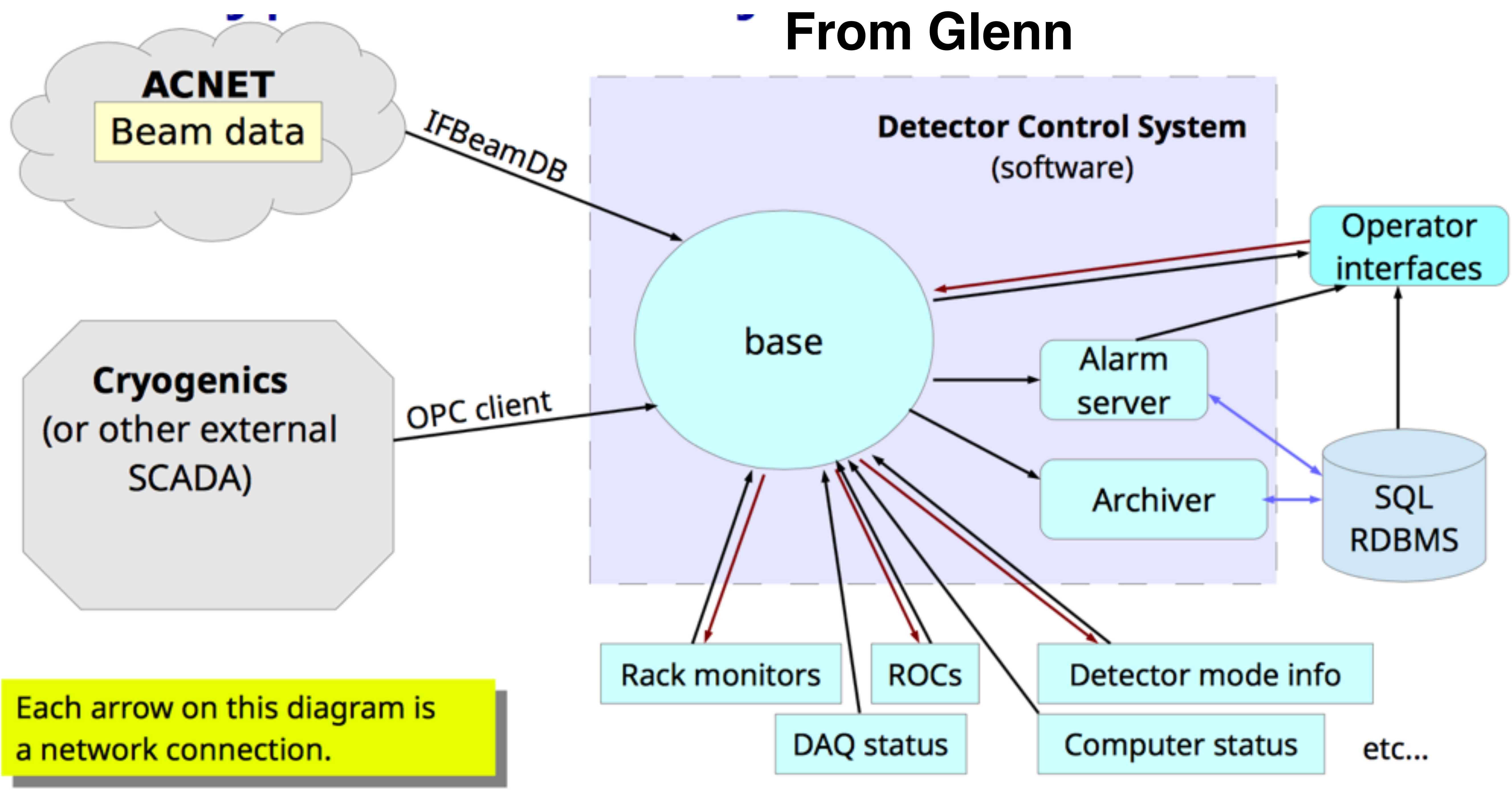
- Light emitting system
  - LED strips

ProtoDUNE-SP R&D
(E. Valencia)



Slow Controls: Typical Work flow

- *Short term goals:* Define requirements and layout for hardware including common rack layout and packaging; Define slow controls software/firmware for all software components



Key Risks and Concerns

Full list: https://docs.dunescience.org/cgi-bin/private/ShowDocument?docid=7192

Risk/Concern	Mitigation Strategy
The baseline design (extrapolated from ProtoDUNEs) for any of the instrumentation devices is not adequate for DUNE far detectors	Detect potential problem ASAP (soon after ProtoDUNE data taking starts) so R&D on alternative designs can proceed on a reasonable time scale. The concept of alternative designs should exist by TDR
Ensuring longevity of devices for 20+ years	Make provisions for for replacement after certain period of time in case of failure or loss of sensitivity.
Instrumentation devices can induce noise in cold electronics	Review grounding & Shielding; Review design parameters and analyze for possible sources during testing
Discrepancies between measured temperature map and CFD simulations in ProtoDUNE-SP	Improve simulations with more precise inputs from real measurements: liquid argon flows, temperature of incoming LAr and temperature of gas argon in the ullage, etc. Use a fraction of T-sensors to predict temperatures in others.
The baseline design of the Cryogenics Instrumentation Test Facility (CITF) is not able to accommodate some of the alternative designs mentioned (related to risk 1)	The constraints of the CIFT should be taken into account when designing new prototypes, so that such that those new designs can be easily accommodated in the CIFT.
During R&D phase the CISC consortium is not able to build a working prototype for cold cameras that meet all the requirements & safety	Further pursue R&D: Improve thermal insulation and heaters, use alternative camera models, etc. If problems persist use cameras at the ullage with the appropriate field of view and lighting such that elements inside LAr can be inspected.
HV Discharge caused by cameras and other devices; HV discharge destroying cameras	Electric field in the camera housing and related anchoring systems must be studied carefully such that the proper shielding is used. Eventually those could be tested in a HV testing facility
Lack of involvement/expertise and insufficient input from past experience for DP technology	Seek help from Technical Coordinator and Spokespeople to ensure DP expetise and involvement is provided at the needed level to the Consortium. Information transfer from DP side is criticial when direct involvement and contribution is not possible.